Novel Design for Less Usage of Ore-Based Materials in Building Construction

by

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CERTIFICATION OF APPROVAL

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Approved by,

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(A.P. Dr Amirhossein Malakahmad)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

KOK JIAN HAO

ABSTRACT

Mankind has spent majority of the non-renewable resources trying to manipulate the natural environment to better suit needs to their daily lives. Construction sector provides basic infrastructure facilities for human's daily activities but nevertheless, environmental issues like global warming has occurred due to an increase concentration of greenhouse gases in our environment. Abundance of carbon dioxide is emitted due to the burning of fossil fuels to obtain energy in the construction activity. This study focuses on the researches on less usage of ore-based materials and aims to reduce the environmental impact of building materials in construction. Various alternative building materials include the use of recycled materials in concrete mixtures, the wood, bamboo and straw bale are identified, analyzed and evaluated in terms of their environmental impacts to achieve low carbon footprint in building construction. The conventional and alternative building materials are compared based on extensive literature review and a carbon calculator is used to determine the carbon-friendliness of the building materials. The alternative building materials which have lesser environmental impact are suggested to be utilized in an office building.

ACKNOWLEDGEMENT

The completion of this project will not be a success without the helps and generosity of many people. Hereby, I would like to acknowledge my heartfelt gratitude to those I honor.

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CHAPTER 1:
INTRODUCTION

1.1 Project Background

Concern about the environment and the future of our planet has become the focal point of everyday conversation. Construction industry possesses significant environmental, social and economic impacts on the society. Construction activities provide buildings and facilities to satisfy human being's requirements in daily life, encourage employment opportunities directly and indirectly, and contributing toward the national economy development. However, in encouraging the country's development, buildings and construction activities have bring negative impacts to our environment, social and economy. During the construction stage, noise, dust (air pollution), traffic congestion, water pollution and waste disposal issue is present. A large amount of natural and human resources is required for the construction. The greenhouse gas emission which contributes to global warming, disposal of buildings which associated with energy consumption and waste production are all the concerns for construction activities. Therefore, "sustainable development" was developed by the World Commission on Environment and Development (WCED), giving the definition which is to ensure sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs. (E.Glavinich, 2008)

In today's world, private and public owners are increasingly requiring that their building projects be designed and constructed in an environmentally responsible manner, to be recognized as a green building. According to American Society of Testing and Materials (ASTM) Standard E2114-06a, green building is defined as a building that provides the specific building performance requirements while minimizing disturbance and to improve the functioning of local, regional and global ecosystems both during and after its construction and specified service life. Green building seeks to reduce waste of energy, water and materials used during construction.

In the study from E.Glavinich (2008), it is about minimizing the environmental impact of the construction process on the environment through procurement, site layout and use, energy use, waste management and construction operations, during the construction. The materials and installation techniques based on expertise and experience are expected to minimize operation and maintenance (O&M) costs over the life of the building, provide a more durable facility, reduce building-related illness that impact the well-being and productivity of building occupants, and maximize the reuse of building materials at the end of the building's life.

1.2 Problem Statement

Construction industry contributes tonnages of the carbon dioxide emission and threaten the health of our environment. While the constructions of buildings increasing the life quality of human beings and bringing wealth to the country, the problem of global warming is highlighted, causing the average surface temperature of the Earth to rise, due to an increase concentrations of greenhouse gases. Abundance of carbon dioxide is emitted due to the burning of fossil fuels to obtain energy in the construction activity. The use of energy derived from fossil fuels in the production of materials, during the construction process, and by the occupants or users of the building or structure throughout its lifetime is a source of significant quantities of carbon dioxide. (Willmott Dixon, 2010)

Furthermore, the construction industry is a conspicuous user of resources. Based on European Commission DG ENV, on March 2011, construction accounts for 24% of global raw materials removed from the earth. Furthermore, the extraction, processing, transport and installation of materials consume large quantities of energy and water. Huge amount of waste are produced throughout the construction cycle, especially at the end of a structure's life. From the study of Willmott Dixon (2010), the excessive construction materials, improper waste management and lack of awareness are very common issues in the construction sites. Much of this wastage is avoidable on site, however inattention to design detailing, inappropriate material, dimensions, late variations, over-ordering are contributing to the waste issue.

1.3 Objectives

This project aims:

a) To reduce the environmental impacts of building materials
b) To reduce the embodied carbon during the manufacture, transport and construction phase
c) To propose the alternative building materials which will ultimately reduce the greenhouse gases emission for the building construction

1.4 Scope of Study

The main focus of the study is to identify the environmental-friendly materials for green building construction. Various sustainable designs and materials usage utilized in the construction today are to be studied and analyzed in order to suggest the suitable design and materials for the green building construction.

Every building project involves the choice of building materials or means used in the selection process. With the evolution of the low-carbon building movement, research and development are increasingly devoting considerable amount of resources to promote and prioritize the use of local and recycled building materials in mainstream practice. (Ogunkah & Yang, 2012)

The scope of study for this project is limited to the embodied carbon of construction materials. Embodied carbon refers to carbon dioxide emitted during the manufacture, transport, construction of building materials, together with its end of life emissions. In construction industry, concrete, bricks and steel are considered as the top carbon emission building material. The study will propose alternative building materials includes the green concrete, wood, bamboo and straw bale which are more environmental friendly and emit lesser carbon dioxide to the environment based on the carbon friendliness of respective materials. The scope of study is highly relevant in order for us to live a sustainable life and the outcomes of the project will justify the feasibility of the alternative building materials in building construction.

CHAPTER 2:
LITERATURE REVIEW

2.1 Criteria for Materials Selection in Building Construction

In any construction project, the selection of building materials in the achievement of green building is essential to be performed both at an early stage of the design process (when general and strategic choices concerning the building are made), and at the working plan (when materials available on the market are selected) (Franzoni, 2011). According to the National Institute of Building Sciences (2013), the composition of materials used in a building is a major factor in its lifecycle environmental impact. For construction of new or renovated building, the use of greener materials and the processes that do not pollute or unnecessarily contribute to the waste stream, do not adversely affect health and do not deplete limited natural resources is important to minimize the environmental impact of constructions. Using a "cradle-to-cradle" approach, the waste from one generation can be utilized as raw material of the next. The recycling and reuse of construction and demolition (C&D) materials offsets the impacts associated with the input of virgin material into construction and renovation of buildings and infrastructure.

According to the study of the Government of South Australia, Department of Planning, Transport and Infrastructure (2012), there are two main streams to consider when selecting green materials associated with the building and construction over a building life cycle functions. Figure 2.1 indicating the key categories of the green building selection criteria for materials, products, components and assemblies and it broadly outlines the two streams and their component parts:

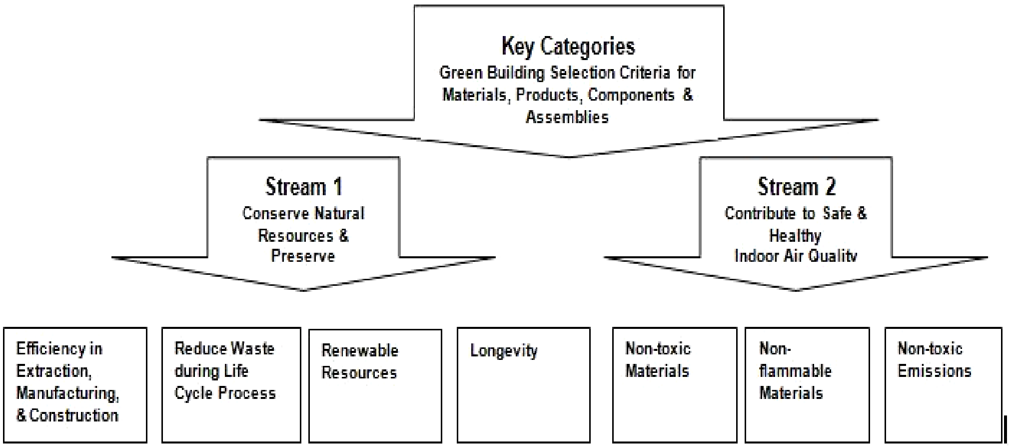


FIGURE 2.1. Key Categories of Green Building Materials Selection Criteria (Government of South Australia, Department of Planning, Transport and Infrastructure, 2012)

From the study, the first stream of the key categories is the preservation of the earth's finite resources through more efficient extraction, production and construction process. Green building materials usage promotes conservation of dwindling non-renewable resources. The integration of green building materials into construction helps in reducing the environmental impacts associated with the extraction, transport, processing, fabrication, installation, reuse, recycling and disposal of these building industry source materials.

The second stream of the material criteria relates to the impact of the materials and their derivatives on building occupants because of their potential to adversely affect the indoor air quality. The material selection will be the integral part of the indoor environment as people spend most of their time indoor and the materials should be non-toxic, non-flammable and do not emit toxic gases. (Government of South Australia, Department of Planning, Transport and Infrastructure, 2012)

Besides that, the overall material use can be reduced by optimizing building size and module. The functional relationships between program spaces and shortening circulation can be optimized, by adhering to space criteria, and individual spaces can be configured to accommodate several complementary functions. Furthermore, buildings are designed to minimize cut-offs and optimize purchasing to prevent excess materials from arriving at the job site. Preference is given to locally produced materials with low embodied energy content to stimulate local economies and reduce transportation burdens and greenhouse gas generation. (National Institute of Building Sciences, 2013)

2.2 Green Building Materials

Early work by Franzoni (2011), defined green building materials as sustainable during their whole life-cycle and not hazardous for human health. Green building materials are generally considered as environmentally friendly or environmentally responsible materials. Materials and permanently installed equipments are critical in green building construction because they represent a major portion of criteria used to classify or certify a green building. The design team specifies the materials and equipments that will be incorporated into the building, while the contractor and its subcontractors are required to understand the material and equipment specifications as well as the characteristics that make the specified materials and equipment green. Thus, this makes material and equipment procurement a critical success factor in any green construction project. (E.Glavinich, 2008)

A recent study has compared the environmental impact of a range of building materials. Energy consumption, carbon dioxide emissions and water demand can all be reduced by switching to renewable sources of energy, improving technologies and promoting eco-friendly alternative materials (European Commission DG ENV, 2011). The results of the study provide approximations of the real environmental impacts of building materials. Constructing buildings with wooden structures would lower the primary energy demand and could be almost carbon neutral, or even carbon negative if the wood was recycled and reused at the end-of-life. In addition, other construction materials such as steel, aluminium, copper, glass and PVC should be reused and recycled where possible to reduce the primary production of these materials. For instance, producing secondary steel (e.g. using scrap steel) could reduce carbon emissions by 74%, compared with producing the same amount of primary steel. (European Commission DG ENV, 2011).

The subsection below showing the discussion on the several alternative building materials includes green concrete, wood, bamboo and straw bale to analyze on its strength and suitability to be used as green building material in a building.

2.2.1 Concrete

The major environmental impact of concrete is caused by CO_2-emissions during cement production as a result of the calcinations and grinding process. It is essential to improve the sustainability of concrete structures, to ensure the future competitiveness of concrete as a building material. (Proske et al., 2013)

According to the research from Proske et al., (2013) on "Eco-friendly concretes with reduced water and cement contents – Mix design principles and laboratory tests", the principles for the development of low-carbon concrete with the efficient use of reactive materials was devised and the following key steps are recommended: (1) Selection of cement of a high strength class and eco-friendly constituents such as limestone, granulated blast-furnace slag (GBFS) or fly ash, (2) Optimization of water content and cementitious material in the concrete paste, and (3) Optimization of the paste volume.

In the studies conducted by Maier and Durham (2012), the effects of several recycled materials, in varying amounts on the concrete properties were investigated. The recycled materials used in this study consisted of ground granulated blast furnace slag (GGBFS), recycled concrete aggregate (RCA) and crushed waste glass.

The production of Portland cement requires significant amount of energy, and it emits lots of carbon dioxide (CO_2) into the environment. The significant source of the CO_2 comes from the high temperature kilns used in the Portland cement production plants. Among all the materials used in concrete today, Portland cement appeared to be the largest contributor to greenhouse gases. In this study, the cement was replaced with ground granulated blast furnace slag (GGBFS). GGBFS, also referred to as slag cement, is a byproduct of the iron manufacturing industry. Slag cement is a hydraulic cementitious material that has pozzolanic characteristics in which the pozzolans react with by-products of the cement hydration process in order to develop strength characteristics in concrete. A moderate amount of cement is required, to produce strength in the concrete. Slag cement possesses cementitious properties much like cement, and will hydrate and produce strength alone when mixed with water. (Maier & Durham, 2012)

In acquiring the aggregates from the Earth, considerable energy must be used to quarry and refine the rock before being used in concrete. Mining operations are always at the forefront of environmental debate not only from the destructive aspect, but also from an aesthetic standpoint. There are different forms of aggregate replacement have been used in the past, from recycled automotive tires and waste metal to pure trash. From the recent researches, recycled concrete aggregate (RCA) is the coarse aggregate replacement that gaining interest. In this study, the coarse aggregate was replaced with the recycled concrete aggregate (RCA) which comes from the demolition of buildings, sidewalks and streets. Another less common aggregate replacement that is gaining more attention is the use of recycled glass as a fine aggregate replacement. (Maier & Durham, 2012)

In the study conducted by Maier & Durham (2012), in order to fully investigate on the effects of these recycled mixtures on the concrete, six mixtures with varying amounts of recycled material replaced were developed, batched and tested for structural and durability performance. Concrete mixtures containing 100%, 75%, 50% and 25% on slag cement, RCA and waste glass was designed, batched and tested. A mixture that contained 100% recycled aggregates and 100% cement is used as a control mixture for the experiment. Table 2.1 shows the concrete with six different mixture designs and proportions.

TABLE 2.1. Concrete Mixture Design (Maier & Durham, 2012)

Mixture	Identification	Descriptions
1	CC (Control)	100% Portland cement; 100% virgin aggregate
2	100-RA-C	100% Portland cement; 100% RCA and waste glass as coarse and fine aggregates
3	100-RA-BF	100% slag cement; 100% RCA and waste glass as coarse and fine aggregates
4	25-RA-BF	25% slag cement and 75% Portland cement; (25% RCA, 75% virgin rock), (25% waste glass, 75% virgin sand)
5	50-RA-BF	50% slag cement and 50% Portland cement; (50% RCA, 50% virgin rock),

		(48% waste glass, 52% virgin sand)
6	75-RA-BF	75% slag cement and 25% Portland cement; (75% RCA, 25% virgin rock), (73.7% waste glass, 26.3% fine aggregate)

The strength of concrete and air content are inversely proportional. The compressive strength of concrete decreases 5.0% for every 1.0% increase in air content (Mindess, Young, & Darwin, 2003). The data are necessary to be normalized in order to determine and evaluate accurately on the results of this research. Figure 2.2 showing the average "normalized" compressive strength development of concrete over time.

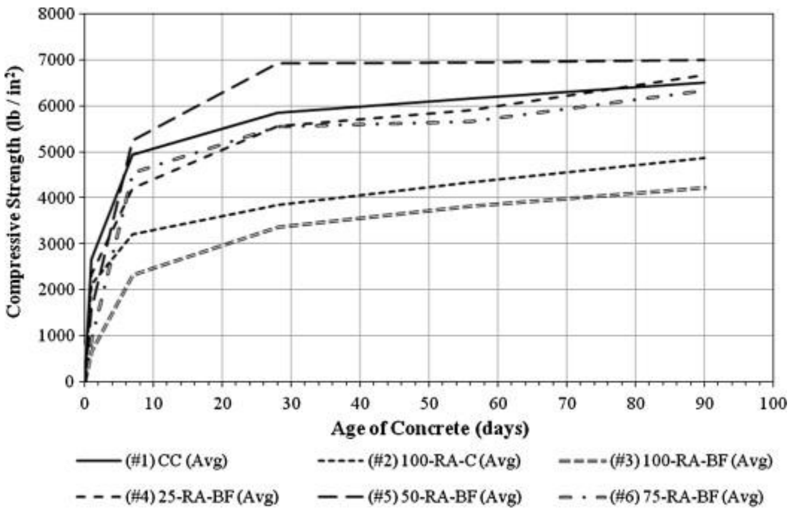


FIGURE 2.2. Average "Normalized" Compressive Strength Development (Maier & Durham, 2012)

From Figure 2.2, the mixture 5 (with 50% recycled mixture) developed the concrete strength rapidly and has the highest compressive strength over time amongst other design mixtures. The mixture 5 outperformed the control mixture by nearly 1000 psi at 28-days and 500 psi by 90-days.

Permeability plays an important role in the property of concrete. Susceptibility to chemical attack and corrosion of reinforcement are both directly related to a concrete permeability. In the study, the decrease in permeability for Mixtures 4,5,6 can be attributed to the pozzolanic reaction that takes place between the slag cement and the calcium hydroxide (CH) released during the hydration process. This drop in permeability occurs when slag cement (pozzolanic material) is used. Table 2.2 showing the rapid chloride penetrability test (RCPT) conducted in the experiment to obtain the permeability of the six different design mixtures.

TABLE 2.2. Rapid Chloride Ion Penetrability Test (RCPT) (Maier & Durham, 2012)

Mixture identification&num (Coulombs)		28-Day (Coulombs)	56-Day (Coulombs)	90-Day (Coulombs)
1	CC (Control)	2106 (Mod.)	1972 (Low)	1969 (Low)
2	100-RA-C	2907 (Mod.)	2212 (Mod.)	1773 (Low)
3	100-RA-BF	578 (V. Low)	406 (V. Low)	321 (V. Low)
4	25-RA-BF	1602 (Low)	1326 (Low)	1327 (Low)
5	50-RA-BF	1041 (Low)	1003 (Low)	874 (V. Low)
6	75-RA-BF	516 (V. Low)	424 (V. Low)	403 (V. Low)

The freeze thaw durability of a concrete is directly related to concrete's strength, permeability and air content. Concrete is porous by nature and will absorb water. Table 2.3 showing the freeze-thaw testing results indicating the durability for all design mixtures.

TABLE 2.3. Freeze-Thaw Testing Results for All Mixtures (Maier & Durham, 2012)

Mixture identification & num		Air content (%) (Hz)	28-Day strength lb/in2 (MPa)	Dynamic modulus (P)	Number of cycles (N)	Durability factor (DF)
1	CC (Control)	10	4300 (29.6)	96.5	320	103
2	100-RA-C	5.2	4375 (30.2)	68.1	272	64
3	100-RA-BF	4.6	3836 (26.4)	56.5	259	49
4	25-RA-BF	6.4	5604 (38.6)	94.5	310	98
5	50-RA-BF	7	6674 (46.0)	95	320	102
6	75-RA-BF	7.5	5148 (35.5)	84.5	310	88

From the research by Maier and Durham (2012), a replacement level up to 50% with recycled materials were determined to be non-detrimental to a concrete mixture with regards to hardened properties, and was determined to be the optimum replacement level. This 50% recycled materials replacement actually enhanced the concrete properties. A reduction in quality began to manifest at 75% and was fully visible at 100% replacement.

The replacement of natural virgin aggregates with RCA and crushed waste glass decreases the workability of a concrete mixture. From the experiment, a small amount of virgin aggregates (25%) will greatly improve the workability and the effects of high range water reducing admixture (HRWRA) which was used on mixtures to achieve workability.

The use of waste glass aggregates without the inclusion of slag cement brings detrimental effects on the hardened properties of a concrete. The mixture with 100% PC and waste glass as aggregate is not a reasonable choice as the potential for (alkali-silica reactivity) ASR expansion is high, while the use of 50% slag cement as cementitious was found to mitigate these expansions to a negligible level.

Table 2.4 summarizes on the effects of varying amount of recycled material on the strength, permeability and durability of the concrete.

TABLE 2.4. Effects of Varying Amount of Recycled Material on Concrete

Replacement amount of recycled material	50%	25%
Effect	Beneficial	Beneficial
Strength	Greater Strength (Ultimate strength of 48.3 MPa with 6.5% air content at 28-days of age	Ultimate strength of 46.3 MPa with 6.5% air content at 90-days of age
Permeability	Much lower than the control concrete	Equal to control mixture
Freeze-thaw durability	Substantial and not affected by recycled materials	Equal to control mixture
Replacement amount of recycled material	75%	100%
Effect	Non-detrimental	Detrimental
Strength	Ultimate strength of 43.8MPa with 6.5% air content at 90-days of age	Ultimate strength of 29.0MPa with 6.5% air content at 90-days of age
Permeability	Significant lower than control mixture	Significant lower than control mixture

Freeze-thaw durability	Significant lower than control, but still considered satisfactory	Very low

2.2.2 Wood

Based on the studies from Sathre and O'Connor (2008), wood has been a primary building material used in construction and it is a sustainable and renewable building material. The utilization of wood in construction is able to (1) lowering fossil-fuel consumption in manufacturing compared with alternative materials, (2) avoiding emissions from cement processing, (3) accumulating carbon storage in wood products and forests, (4) avoiding fossil-fuel emission due to biomass substitution, and (5) playing a part in carbon dynamics in landfills. The studies by Canadian Wood Concil (2002), showed that wood is the best solution for satisfying the four principle of green building: 1) reducing energy use during building service life, 2) minimizing external pollution and environmental damage, 3) reducing embodied energy and resource depletion and 4) minimizing internal pollution and damage to health.

The building and living with wood concept is formed by a multilayered combination of wood and wood-based materials to serve as a system for working in the construction process of interior design on-site and off-site construction, decoration, renovation, maintenance and associating with the nearby environment. The structural use of wood and wood-based materials is one of the primary choices in residential building and its popularity has increased steadily due to the major driving force which is the ever-increasing need for affordable housing and environmental consciousness. (Wang et al., 2013)

In the studies conducted by Gustavsson and Sathre (2006), they investigated the changes in energy and CO_2 balances caused by variation of key parameters in the manufacture and use of the materials comprising a wood and concrete-framed building. Parameters considered were clinker production efficiency, blending of cement, crushing of aggregate, recycling of steel, lumber drying efficiency, material transportation distance, carbon intensity of fossil fuel, recovery of logging, sawmill, construction and demolition residues for bio-fuel, and growth and exploitation of surplus forest not needed for wood material production. The materials of the wood-framed building were found to have lower energy and CO_2 balances than the concrete-framed building materials. The recovery of demolition and wood processing residues for use in place of fossil fuels contributed most significantly to the lower energy and CO_2 balances of the wood-framed building materials. (Gustavsson & Sathre, 2006)

In this study, the changes in energy balances for material production due to variation of the same parameters is calculated, taking into account the energy used in material production as well as bio-fuels generated during the production and use of wood-based building materials. The changes in energy and CO_2 balances is compared to a reference case which is the "best case" scenario that comprised of parameters that give the lowest energy and CO_2 balances, at which deviations cause a higher energy and CO_2 balance. (Gustavsson & Sathre, 2006)

Reference energy balance

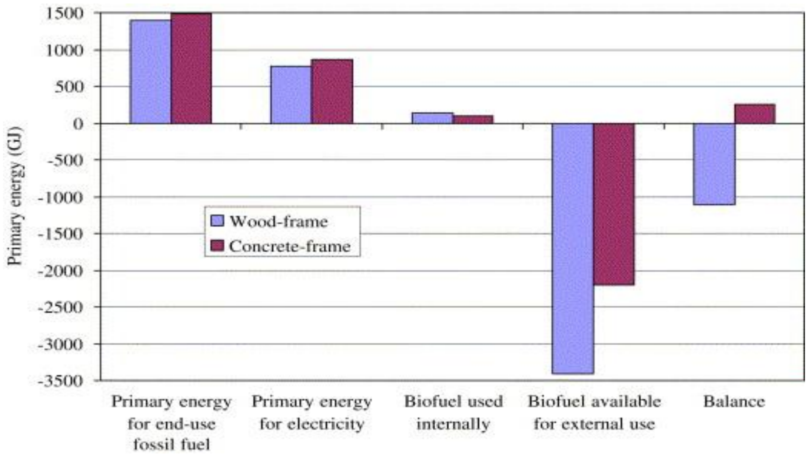


FIGURE 2.3. Contributions to the energy balances (GJ) of the reference case production of all materials for the wood- and concrete-frame buildings (Gustavsson & Sathre, 2006)

Figure 2.3 showing the contributions to the energy balances of the reference case production of materials for the wood and concrete-framed buildings. From the figure, accounting the primary energy for end-use fossil fuel, primary energy for electricity, biofuel used internally, and biofuel available for external use, the overall energy balance is 260 GJ for the concrete-frame building and -1110GJ for the wood-framed building. The biofuel internally in the figure is for the process heat for wood product manufacture, while the biofuel available for external use means the total biomass residues recovered from logging, processing, construction and demolition, minus the biofuel used internally. The negative energy balance indicate that more usable energy in the form of bio-fuel is made available during the lifecycle of the materials than is used during the production of materials. (Gustavsson & Sathre, 2006)

Reference CO_2 balance

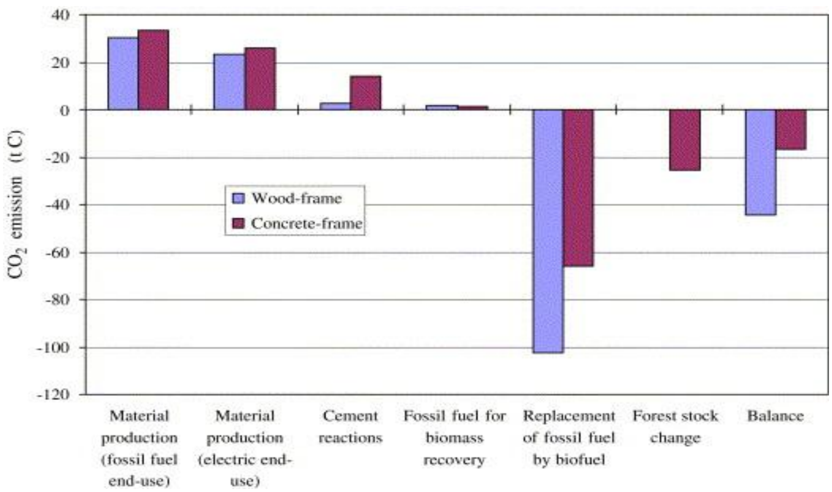


FIGURE 2.4. Contributions to CO2 balances (tC) of the reference case production of materials for the wood- and concrete-frame buildings (Gustavsson & Sathre, 2006)

The CO_2 balances of the reference case production of materials for the two building types are shown in Figure 2.4. Summing up all the CO_2 contributions including the material production (fossil fuel end-use), material production (electric end-use), cement reactions, fossil fuel for biomass recovery, replacement of fossil fuel by bio-fuel and forest stock change, wood-frame building produced emission of -44.2 tons C and -16.5 tons C for the concrete-frame building. The emission is more negative for the wood-frame building due to the lower emission during material manufacture and the greater replacement of fossil fuel by biomass residues. (Gustavsson & Sathre, 2006)

The precise values of the energy and CO_2 balances of building materials depend upon many factors. This study concluded that the use of wood building material instead of concrete, coupled with the greater integration of wood by-products into energy supply systems could be an effective means of reducing fossil fuel use and net CO_2 emission. (Gustavsson & Sathre, 2006)

2.2.3 Bamboo

Bamboo is one of the fastest-growing plants on the planet, and it regenerates in three to five years after harvesting. As a heavily forested country, bamboos are abundant and widely distributed in Malaysia. Forest products like bamboo are important sources of income. In the last decade or so, Forest Research Institute Malaysia (FRIM) has given very high priority for bamboo development, both in terms of growth and manufacturing aspects. (Mohamed & Appanah) At present, it is ranked second to rattan in economic importance in Peninsular Malaysia among the minor or non-timber forest products. (Aminuddin & Latiff, 1991)

In addition, bamboo has a higher fibre density than wood, and resists wear well. As a hard and moisture-resistant material, bamboo is being used increasingly by environmentally-minded builders and homeowners. (Lee & Neely, 2005)

Bamboo, just like timber, is vulnerable to environmental degradation and attacks by insects and moulds. In the studies conducted by Ghavami (2005), there is a strong relation between insect attacks and the levels of starch plus humidity content of bamboo culm. Thus, in order to reduce the starch content, bamboo undergoes variety of treatments including curing on the spot, immersion, heating or smoke. Bamboo with low humidity is less prone to mould attacks and the physical and mechanical properties of bamboo will increase with the decreasing humidity content in bamboo. (Ghavami, 2005)

Several steel and concrete structures built in the past 30 years reveal serious deterioration caused mainly by the corrosion of the steel reinforcement. In 1979, a steel reinforced concrete column after 10 service years and the first bamboo reinforced concrete beam tested at PUC-Rio are presented and compared. It was observed that the bamboo segment of the beam reinforcement which treated against insects as well as for bonding with concrete is still in satisfactory condition after 15 years. However, the steel reinforcing bars of the column are severely corroded and replacement is required. (Ghavami, 2005) Figure 2.5 shows the steel and bamboo reinforcement for the purpose of improving the durability of concrete elements.

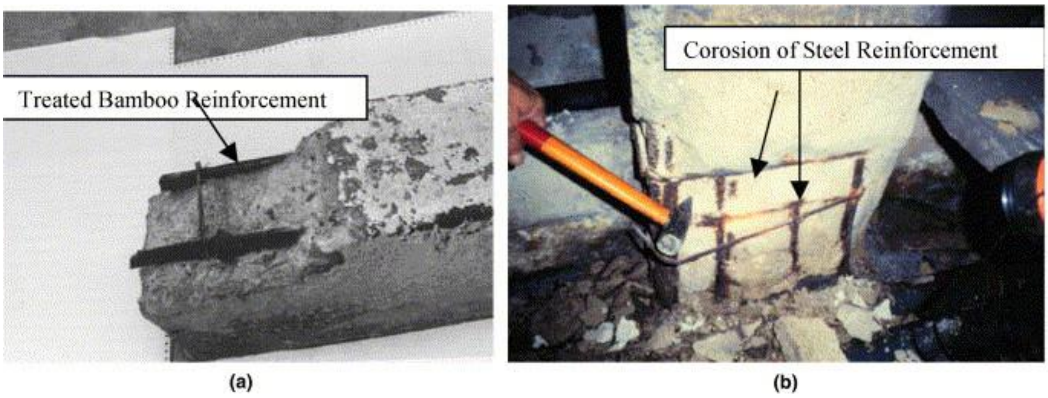


FIGURE 2.5. (a) Bamboo reinforcement of a tested beam exposed in open air after 15 years. (b) Steel reinforcement of a column in the tunnel of metro after 10 years in closed area. (Ghavami, 2005)

Bamboo reinforced concrete beams

In the studies by Ghavami (2005), the simply supported bamboo reinforced concrete beams, fabricated with normal, lightweight and laterite aggregates of 20mm maximum size have been tested. The beam, reinforced with steel bars served as the reference. The test results indicated that the treatment of bamboo prior to use improved the bamboo-concrete bonding by more than 100%. By adopting the bamboo reinforcing ratio, $\rho=3\%$ as the ideal value, the ultimate applied load increased by 400% as compared with concrete beam without reinforcement.

Concrete slabs with bamboo permanent shutter forms

Bamboo finds an efficient application in concrete slabs reinforced with half bamboo sections, which work as permanent shutter forms. Figure 2.6 showing the schematic set up of the concrete slab with bamboo permanent shutter forms and the bamboo of slab during treatment. (Ghavami, 2005)

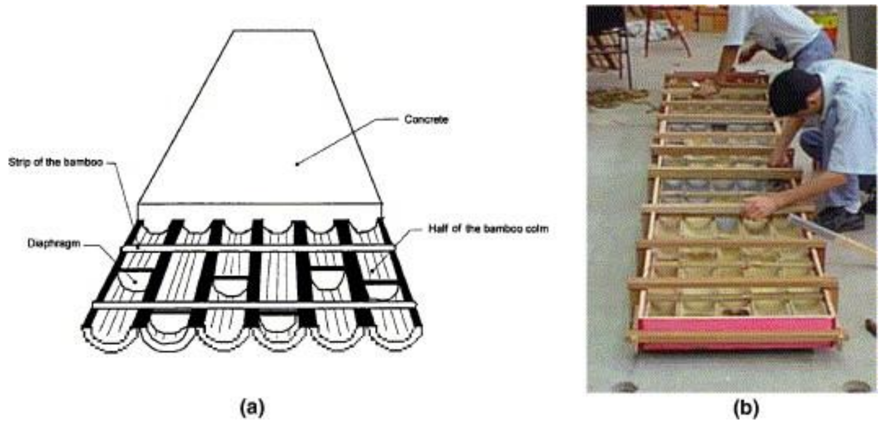


FIGURE 2.6. Concrete slabs reinforced with bamboo permanent shutter forms (a) Schematic set up of the slab. (b) Bamboo of slab during treatment. (Ghavami, 2005)

A half split bamboo culm, which works as a tensile reinforcing bar and also as a permanent shutter form, schematically shown in Figure 2.7 was filled with concrete.

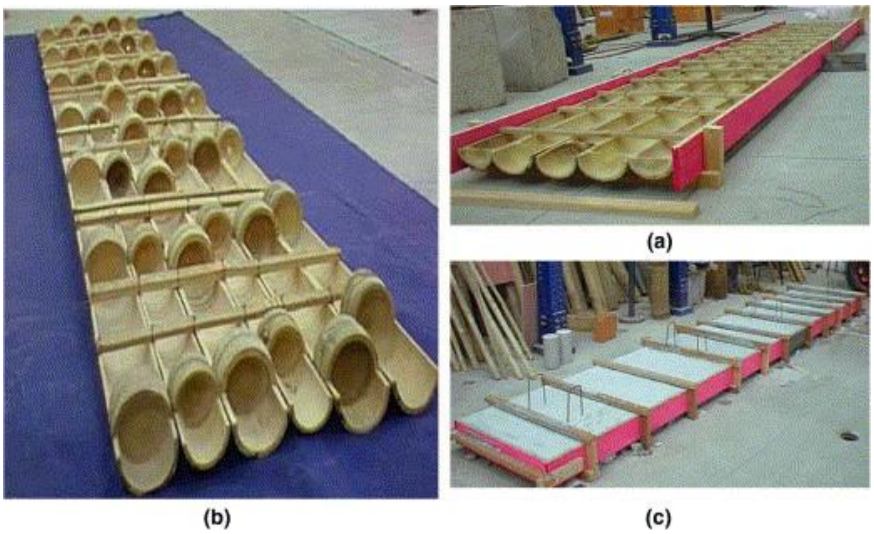


FIGURE 2.7. Concrete slabs reinforced with bamboo permanent shutter forms. (a) Half bamboo diaphragm as connector. (b) Second type of connector. (c) Slab before testing. (Ghavami, 2005)

The shear resistance of whole and half bamboo diaphragms has been studied and it is found out that the shear resistance of the half bamboo diaphragms is not sufficient enough to prevent its shear failure. Therefore, the entire bamboo diaphragm is considered, and a strip of steel or bamboo rod close to the bamboo diaphragm passing through the bamboo diameter was fixed for further improvement. This method doubled the shear strength of the diaphragm hence the ultimate load of the slabs and this type of slab is now successfully used in Brazil. (Ghavami, 2005)

Bamboo reinforced concrete columns

In the study of Ghavami (2005), in order to obtain the data for comparison, a control column of steel reinforcement concrete was prepared using the same mix proportions as for bamboo-reinforced columns. All the columns were cured for 28 days, using wet saw dust before they were tested. The columns were tested in steel frame of 1000 kN capacity and were subjected to increment of 2 kN axial load. The results were both the columns failed almost at the same load showing that bamboo reinforcement would be as good as the conventional steel reinforcement for normal concrete.

The results of the investigations show that bamboo can substitute steel satisfactorily and the structural elements developed could be used in different building constructions.

In the studies conducted by Yu et al. (2011), the bamboo-structure residential building prototype is built to optimally integrate traditional architectural design concepts with innovative insulation technologies. The sustainable, hard and durable bamboo is used as the supporting structures (bamboo columns or beams with steel joints). The strength of bamboo is promising and it is an environmental-friendly material. In order to address the thermal insulation issue of the bamboo-structure building, vacuum insulation panels (VIPs) is embedded between two façade modules to form a prefabricated sandwich structure in the building, which will significantly reduce the thickness of the walls and meet the insulation requirements of the bamboo-structure building.

The bamboo-structure vs. brick-concrete building

A typical brick-concrete building in compliance with contemporary practices is selected as a baseline with the same floor area and window to wall ratio as the bamboo-structure building. Table summarizes the embodied energy and carbon, and thermal resistance of the components of the two types of buildings. It indicates that the bamboo-structure building is 3003.4 MJ/m^2 and 168.9 kg CO_2/m^2 in contrast to the brick-concrete building which has the embodied energy of 3532.9 MJ/m^2 and embodied carbon of 326.1 kg CO_2/m^2. On the other hand, the thermal insulation level of the bamboo-structure building is 6-10 times higher than the brick-concrete building. (Yu et al., 2011)

TABLE 2.5. The embodied energy and carbon of the bamboo-structure and brick-concrete buildings (Yu et al., 2011)

Bamboo-structure building	Weight	Embodied energy	Embodied carbon	Brick-concrete building	Weight	Embodied energy	Embodied carbon
	kg	MJ	kg CO2		kg	MJ	kg CO2
Roof, 8.90 m2 K/W	1850	65,084	4093	Roof, 1.54 m2 K/W	11,848	45,684	4417
Standing seam steel system	876	25,094	1936	Gravel-sand, 5 mm	754	134	26
Steel support system	250	7151	552	Cement mortar, 1:2.5, 20 mm	1912	3136	593
Extruded polystyrene,30 mm	61	5396	152	Expanded perlite concrete,100 mm	2691	25,266	1641
VIPs, 35 mm	499	20,294	1078	Cement mortar, 1:2.5, 20 mm	1912	3136	593
Extruded polystyrene, 20 mm	41	3597	102	Steel-concrete, 35 mm	4257	4768	851
Light-gauge keel	124	3552	274	Light-gauge keel	124	3552	274
Plasterboard, 10 mm	489	3303	186	Plasterboard, 10 mm	489	3303	186
Wall, 10.21 m2 K/W	5092	60,107	3130	Wall, 1.35 m2 K/W	41,710	91,783	7920
Bamboo decorated panel	2689	6938	350	Cement mortar,1:2.5, 20 mm	2758	4524	855
Extruded polystyrene, 20 mm	59	5189	146	Brick, 240 mm	33,394	58,439	4675
VIPs, 35 mm	720	29,274	1555	Expanded perlite concrete, 50 mm	2046	18,997	1303
Blockboard, 10 mm	392	5110	294	Cement mortar, 1:2.5,20 mm	2758	4524	855
Wood keel	333	2317	136	Plasterboard,10 mm	753	5083	286
Extruded polystyrene, 50 mm	146	12,973	366				
Plasterboard, 10 mm	753	5083	286				
Window and door		3740	195	Window and door		3740	195
Window (5.3 m2)		1910	95	Window		1910	95
Door	152	1829	99	Door	152	1830	99
Floor, 8.5 m2 K/W	1639	26,013	1304	Floor, 0.86 m2 K/W	10,314	31,132	3109
Bamboo floor, 18 mm	793	7753	404	Bamboo floor, 18 mm	793	7753	404
Extruded polystyrene, 20 mm	41	3652	105	Wood keel, 3.4 kg/m2	183	1272	75
VIPs,15 mm	214	8697	462	Cement mortar, 1:2.5,20 mm	1912	3135	593
Blockboard, 10 mm	272	3594	201	Expanded perlite concrete, 30 mm	1345	12,633	821
Wood frame	321	2316	132	Concrete, 50 mm	6081	6181	1216
Bamboo column and beam	711	1834	92	Reinforced concrete column	4532	11,604	1383
Value per m2 floor area	348	3003	169	Value per m2 floor area	2540	3533	326

Figure 2.8 and 2.9 showing that there exists a consistent trend of differences between the components of the two types of buildings (the embodied energy and embodied carbon is lower in bamboo-structure building compared with the brick-concrete building). The higher embodied energy for the roofs on bamboo-structure

building results mainly from the different roof areas (i.e., one being curved, and the other flat). Therefore, it is necessary to ascertain whether or not there are intrinsic factors leading to the differences. (Yu et al., 2011)

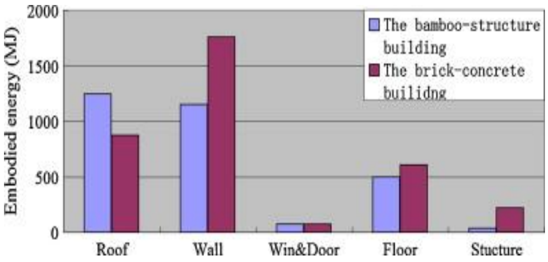


FIGURE 2.8. The Embodied Energy of the Two Types of Buildings (Yu et al., 2011)

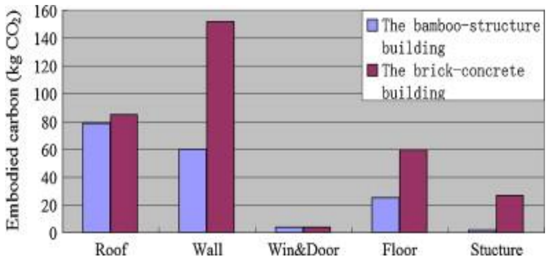


FIGURE 2.9. The Embodied Carbon of the Two Types of Buildings (Yu et al., 2011)

From the studies conducted by Yu et al. (2011), it has shown that the bamboo-structure residential building prototype with innovative insulation technologies has lower embodied energy and carbon than an alternative brick-concrete building with identical functional requirements. Thus, it is implied that the bamboo-structure building has a promising perspective to be one of the sustainable buildings.

2.2.4 Straw Bale

Straw is a natural fiber which we get as a byproduct from the agriculture. It is the baled up dead plant stems of a grain crop (including wheat, oats, barley, rye, rice and hemp), once the seed head has been harvested from the plant (Elsayed). Rice straw is the toughest among the crops, as it has a significant amount of silica, which increases density and resistance to decomposition. Straw is being produced by the process of photosynthesis which is natural and non-polluting process by solar energy. On the other hand, straw is considered as the waste product and it would not decay easily. Thus, it is wasted by burning or any other way which is leaving negative impact on the environment. (Bhattarai et al., 2012)

Straw bale is simply a compressed bundle of straw which is arranged in square, rectangular and round shape attached with wire or twins. The bale density varies according to type of grains, moisture level and degree of compaction provided by the baler. According to the studies conducted by Bhattarai et al. (2012), straw bales are light which means a straw bale wall weight 65% less than an equivalent brick wall and 62% less than concrete block wall.

Environmental Performance

From the studies conducted by Bhattarai et al. (2012), it is indicated that straw bales are highly eco-friendly in its production, placement, function and operation and maintenance to reconstruction. The environmental issue encompasses the following features:

TABLE 2.6. Features of Straw (Bhattarai et al.,2012)

Features	Descriptions
Fire Resistance	Since straw bales are tightly packed making it too dense

	(lack in oxygen), hence it does not support the combustion. The test conducted at the Richmond Field Station in 1997 by student of California Berkeley reflect that timber resist fire for 8 minute, un-rendered straw bale resist fire for 30 min, while rendered straw bale has fire-resistance for 2 hours.
Thermal Insulation	The thick straw wall creates the insulating gap between external and internal part of wall. This helps to resist the flow of heat at higher level and it aids to save energy. Rice straw is a Class A insulating material.
Sound Insulation	Straw is fibrous material which resists the sound waves, controlling noise pollution and helps to save energy.
Structural Capacity	The load bearing straw bale method can withstand up till two-storey homes whereas light-weight frame method helps to improve the stability and building up to three-floors can be made.
Durability and Moisture Resistance	Straw is highly durable in absence of excess moisture (< 15%). It is reasonably expected to have lifetime of 100 years or more, if straw bale is well protected with moderate maintenance.
Resistance against Termites and Pests	Clean and dry straw have less nutrition thus it is unable to support paste population for long in itself. The tightly pressed straw bale also provides fewer spaces for paste to live.
Toxicity and Moisture Resistance	Straw bale is non-toxic and produces no harmful chemicals due to its inert nature. Besides, straw bale having good breathability allowing air to slowly permeate the structure without moisture penetration.
Availability	Straw is agricultural by-product and locally available. It is easily accessible.

From the studies by Elsayed, another leading reason to choose straw bales over other building materials is its high level of energy-efficiency. Table 2.7 indicates the R-value of the conventional wall system and the straw bale walls system.

TABLE 2.7. R-Value of Construction Materials (Elsayed)

Construction	R-Value	Descriptions
Conventional Wall System	2.0 to 3.5	Depending on climatic conditions, building code regulations, building material and type of insulation
Straw Bale Wall System	5.5 to 8.5	Depending on widths, type, quality and density of straw bales and how the bales are stacked

R-value means the capacity of an insulating material to resist heat flow, and the higher the R-value, the greater is the insulating power. Combined with a well-designed passive solar system, straw bale houses require very little energy to keep warm in winter and cool in summer (Elsayed).

Straw is having wide benefits which help in fulfilling in the green concept to some extend due to its tremendous features. Therefore, it can be concluded that straw is a promising materials for the green construction because of its performance in collaboration with the environment.

Cost Efficiency

Three main factors that contributes to the cost efficiency of straw as building materials are straw is a less costly material, renewable resource and it is widely available. It is easily, cheaply available material, requires limited transportation, no transformation process is necessary and it can be easily handled. It does not require much skilled man power for procurement and construction and since it is an agricultural by-product, it helps to reduce the usage of non-renewable resources which create environmental issues. (Bhattarai et al., 2012)

Construction

The three main methods to build with straw bale are:

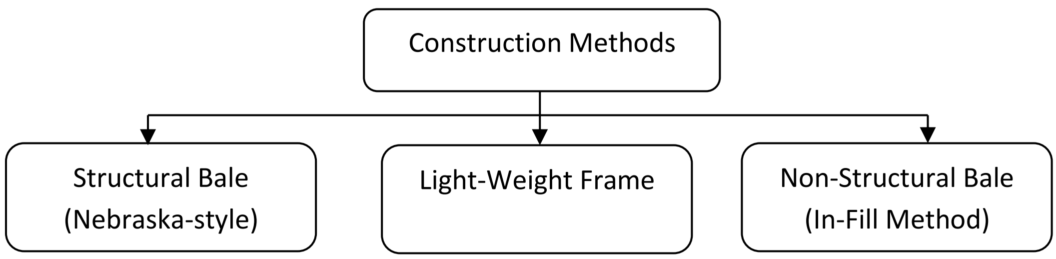


FIGURE 2.10. Methods of Straw Bale Construction (Bhattarai et al.,2012)

TABLE 2.8. Comparative Analysis of Straw Bale Construction Methods (Bhattarai et al.,2012)

No	Type	Load Bearing	Light-Weight Frame	In-Fill Method
1	Construction	Bales are placed	Uses a timber framework	Posts and beams are

	Method	together like building blocks, pinned to the foundations, and the roof is constructed in the usual manner on top of the rood plate	that is so light-weight that it requires temporary bracing to give it stability until the straw is in place.	constructed of timber or steel for form the structural framework and roof is then added, and finally straw bales in-fill the frame work
2	Building Style	Designs from one room to two-storey homes can be created using a simple, step by step approach.	Building up to three floors can be made.	Any number of floors can be constructed since the weight is supported in the frame.
3	Load Distribution	The bales take the weight of the roof	Straw works together with the timber to carry the load of floors and roof	The weight of roof is carried by wood, steel or concrete framework, bales are simply infill insulation blocks between the posts.
4	Amount of support materials needed	Minimal use of timber	Vastly reduces the amount of timber required	Requires more timber than load bearing design
5	Stability and Size of Openings	Low stability for windows and doors in the wall	Greater stability than load bearing style	Greater stability than load bearing style
6	Subjection to Wetting	Straw must be kept dry throughout building process until it is plastered.	The roof can be constructed before the straw is placed providing secure weather condition	The roof can be constructed before the straw is placed providing secure weather condition
7	Speed of Construction	Fast	Take more time than load bearing method	Take more time than load bearing method
8	Need of skills	Easy for non-professionals to design	Greater technical ability is required	High level of carpentry skills is required

Table 2.8 showing the comparative analysis of the three different straw bale construction methods from the studies done by Bhattarai et al. (2012).

In the emerging world where the rising demand for housing is increasing due to tremendous growing of rural and urban population has been a pressuring issue. Straw Bale can be one of the promising building material that meet the overall housing need and energy efficient goal of most developing countries. Thus, profound research and awareness regarding straw bale construction should be enhanced in developing land agriculture countries for effective implementation of straw bale house. (Bhattarai et al., 2012)

CHAPTER 3:
METHODOLOGY/PROJECT WORK

3.1 Research Methodology

In order to reduce the environmental impact in the building construction, several green building materials that are being utilized in the construction building all around the world especially in the tropical country like Malaysia as alternative building materials are identified. The analysis of the materials is performed to figure out the advantages and disadvantages of using the resources includes the green concrete, wood, bamboo and straw bale in the building construction.

The building materials are to be selected for the construction of an office building in UTP. Comparison of the building materials will be performed based on the extensive literature review, identification of the materials' local availability and calculation of the materials quantities required for the building construction. These information of the materials transportation distance, and material quantities will be entered into a carbon calculator to measure the carbon dioxide equivalency of both the conventional and alternative building materials. The building materials will be compared graphically based on their embodied carbon dioxide for the different building sections in the proposed office building, to determine the impact and carbon-friendliness of the alternative building materials over the conventional building materials. The justified building materials will be recommended in the office building based on the results according to the embodied carbon dioxide.

3.1.1 Carbon Calculator

In this project, a carbon calculator developed by Environment Agency will be used by the other co-operated project to measure on the greenhouse gas impacts of construction activities in terms of carbon dioxide equivalency (tCO2e). Figure 3.1 showing the procedures of the carbon calculation for the building materials.

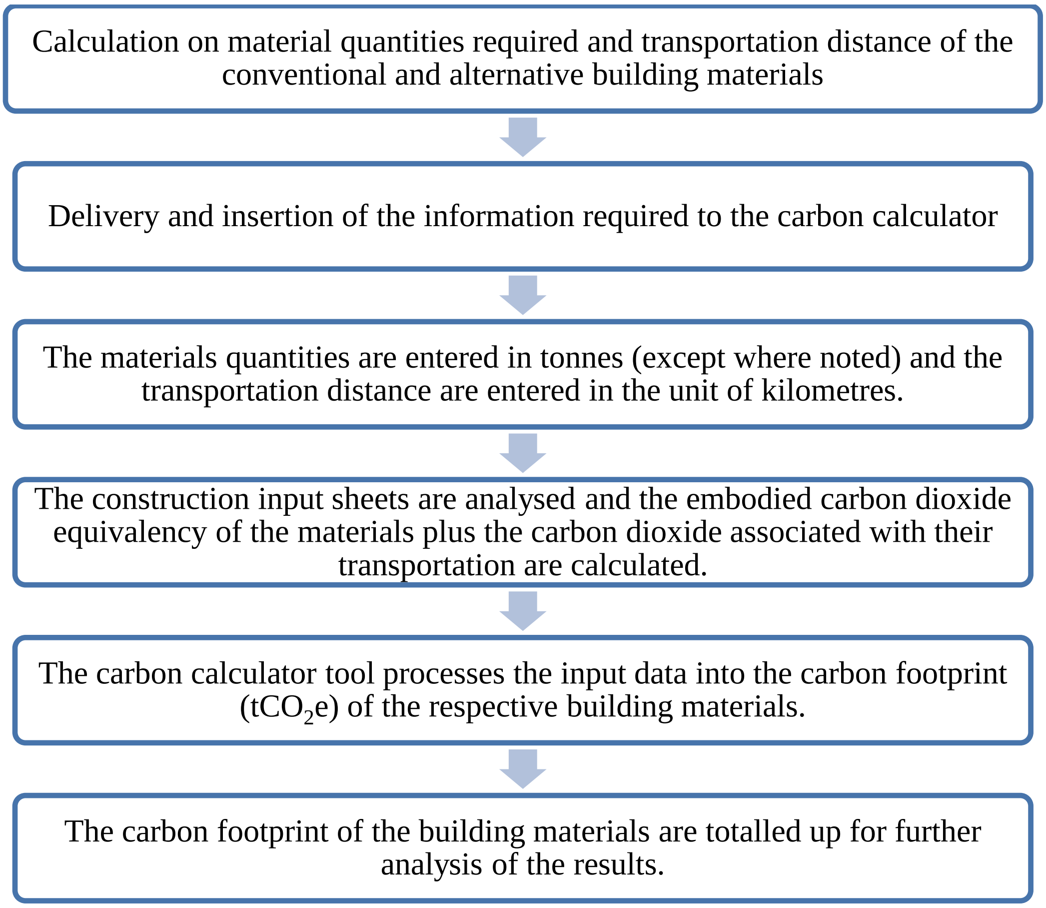


Figure 3.1 Carbon Calculation Procedures

The calculation of the carbon dioxide equivalency is co-operated with the other FYP project and the results obtained will be used in this study for the justification of the materials in building construction.

3.1.2 Project Flow Chart

Figure 3.2 summarizes the project process flow chart that will be used throughout the project period:

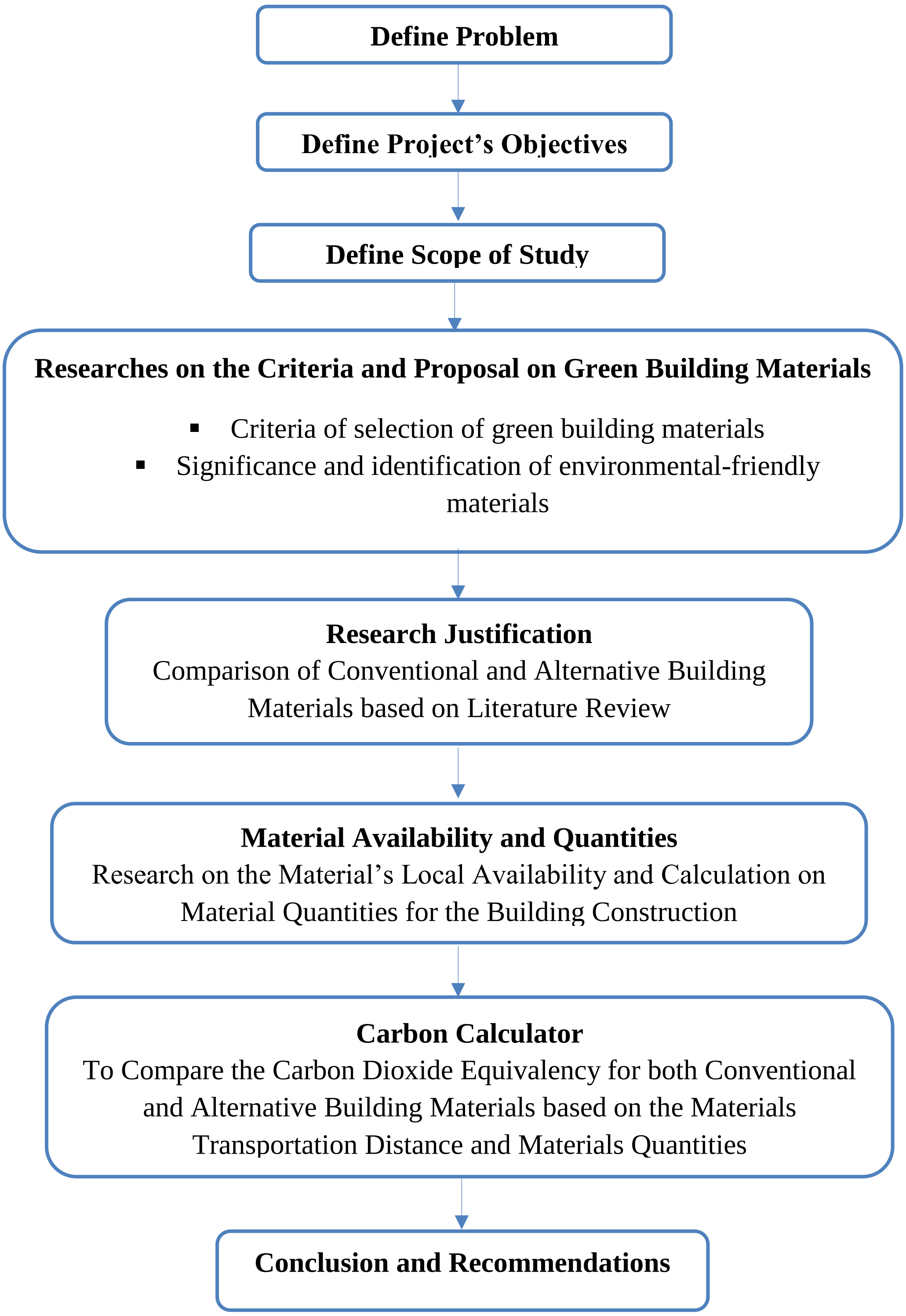


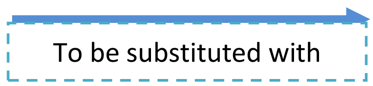
FIGURE 3.2.   Project Process Flow Chart

3.2 The Rationale of Selection of Building Materials

The selection of the alternative building materials are assisted by key categories of the green building selection criteria for materials developed by the Government of South Australia, Department of Planning, Transport and Infrastructure (2012). The alternative building materials include the low-carbon concrete, wood, bamboo, and straw bale are fall under the stream 1 which is the materials that conserve and preserve the natural resources, and stream 2 which contribute to the safe and healthy indoor air quality.

The comparison of the conventional and alternative building materials is shown in Table 3.1:

TABLE 3.1.   The Comparison between Conventional and Alternative Building Materials



No.	Conventional Building Materials	Alternative Building Materials
1	Conventional Concrete: - Cement - Coarse Aggregate - Fine Aggregate	Use of Recycled Materials in Concrete Mixtures (Green Concrete): - Ground granulated blast furnace slag (GGBFS) / Slag Cement - Recycled Concrete Aggregate (RCA) - Recycled Glass (Crushed waste glass)
2	Concrete Wall System / Brick Wall System	Straw Bale Wall System
3	Steel Reinforcement Structure - Steel Reinforced Concrete Beam - Steel Reinforced Concrete Column	Bamboo Reinforcement Structure - Bamboo Reinforced Concrete Beam - Bamboo Reinforced Concrete Column
4	Concrete Flooring	Wood Flooring / Bamboo Flooring

From Table 3.1, firstly, the conventional concrete which made up of cement, coarse aggregate and fine aggregate is proposed to be substituted with the green concrete which consists of the slag cement, recycled concrete aggregate and recycled glass. The best concrete combination mixture (50% on the conventional and 50% on recycled mixtures) based on the study by Maier and Durham (2012), which resulted in the concrete with higher compressive strength, lower permeability and substantial durability is taken as the green concrete used in this research project. This green concrete with the stated proportion of recycled mixtures will be used for comparison with the conventional concrete.

The conventional wall system which usually made up of concrete or bricks is compared with the straw bale wall system in terms of its weight and carbon emission. In the emerging world where the rising demand for housing is increasing due to tremendous growing of rural and urban population has been a pressuring issue. Straw Bale can be one of the promising building material that meet the overall housing need and energy efficient goal of most developing countries. (Bhattarai et al., 2012)

Then, the bamboo reinforcement which is utilized as the beam and column reinforcement with proven strength and durability is proposed to replace the steel reinforcement system. The results of the investigations show that bamboo can substitute steel satisfactorily and the structural elements developed could be used in different building constructions. (Ghavami, 2005)

3.3 Tools Required

During the project period, most of the information is obtained from the e-resources in the Information Resource Centre (IRC) of Universiti Teknologi Petronas (UTP). The information is collected from the published journal articles in the subscribe databases such as Science Direct which has over 1500 scientific, technical and medical peer-reviewed journals from Elsevier.

In this project, a carbon calculator developed by Environment Agency will be used by the other co-operated project to measure on the greenhouse gas impacts of construction activities in terms of carbon dioxide equivalency (tCO_2e), in order to determine on the carbon friendliness of the building materials.

3.4 Gantt Chart

Figure 3.3 showing the Gantt chart and the key milestone for the project in Final Year Project I (FYP I) and Final Year Project II (FYP II):

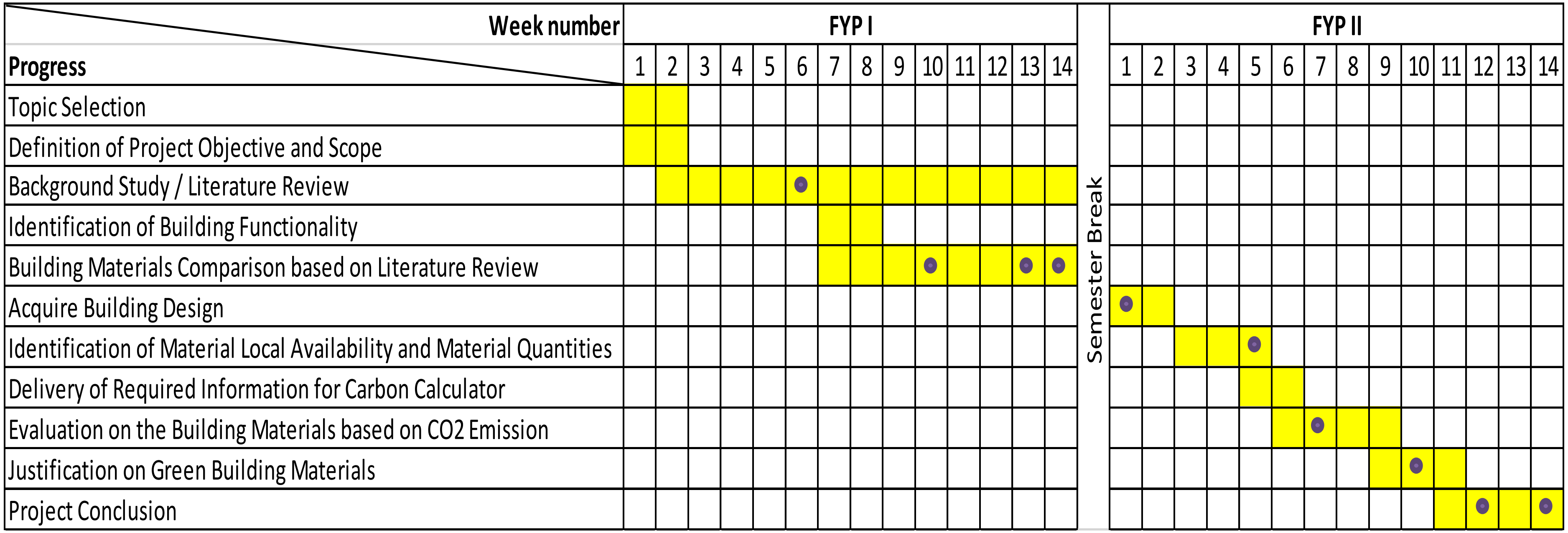


FIGURE 3.3. Gantt Chart of Project

Key Milestone

3.4.1 Key Project Milestone

Table 3.2 indicates the key project milestone for both FYP I and FYP II.

TABLE 3.2. Key Project Milestone for FYP

Time (Week)	Key Activities	Remarks (Status)
FYP I		
6	Submission of Extended Proposal	Completed
10	Proposal Defence	Completed
13	Justify method to acquire building design and carbon emission calculation	Completed
13	Completion on the selection of alternative building materials	Completed
14	Submission of Interim Report	Completed
FYP II		
1	Acquire Building Design	Completed
5	Justification of the conventional and alternative building material (based on literature review)	Completed
7	Researching on the local availability of material and calculation of material quantities	Completed
7	Evaluation of the conventional and alternative building material in terms of carbon dioxide equivalency	Completed
7	Submission of Progress Report	Completed
10	Graphical representation on the comparison of conventional and alternative building materials	Completed
10	Pre-Sedex	Completed
12	Submission of Technical Paper	Completed
12	Submission of Dissertation (Soft Bound)	Completed
14	Viva	Completed
15	Submission of Project Dissertation (Hard Bound)	Completed

CHAPTER 4:

RESULTS AND DISCUSSION

4.1 Building Design

A conceptual office building is designed with respect to the objective which is to ultimately reduce the carbon footprint of a building by utilising the building materials that contribute minimal environmental impact.

The office building will proposed to be served as a green resource centre, to house the staffs (researchers, engineers, architects or environmentalist) who are working on low carbon and environmental-friendly design and material usage of a building. The location of the office building will be proposed at Universiti Teknologi PETRONAS (UTP), Tronoh, Perak, Malaysia. This green resource centre aims to create the awareness of the impact of green movement in construction in our life and to provide tours for professionals, students and public to deliver the information about the environmental-friendly building construction to the people around.

The following table and figures showing the details and dimensions of the proposed office building. There are two floors for this office building and Table 4.1 summarize the dimensions of the building:

TABLE 4.1. The Building Dimensions

Building Dimension	Dimension (m)
Height (Ground Floor)	4.50
Height (First Floor)	3.50
Height (Roof)	2.20
Length	30.00
Length (With Roof)	34.00
Width	15.00
Width (With Roof)	21.35

The following figures showing the north, south, east and west elevation of the proposed office building:

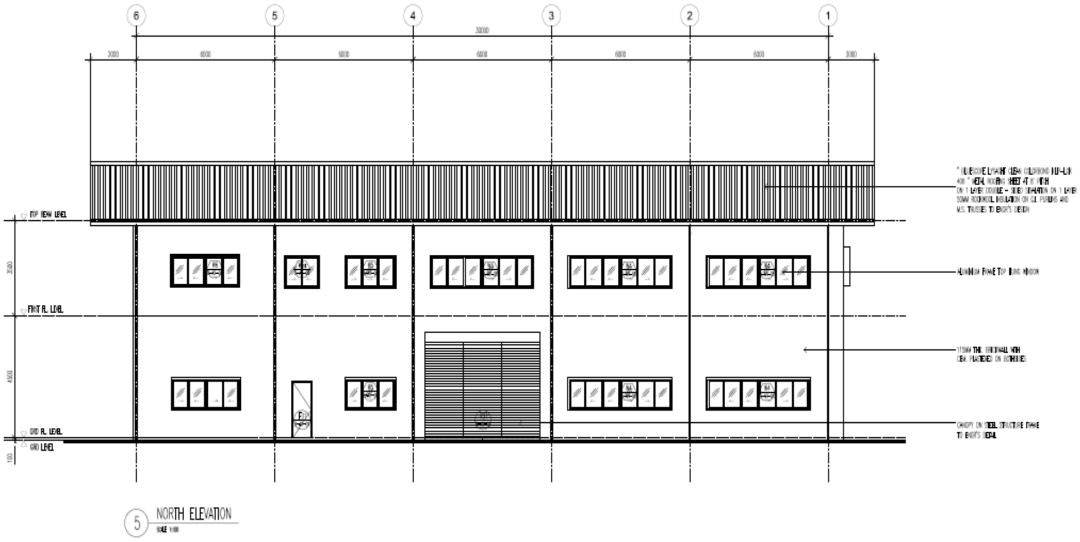


FIGURE 4.1. North Elevation of the Office Building

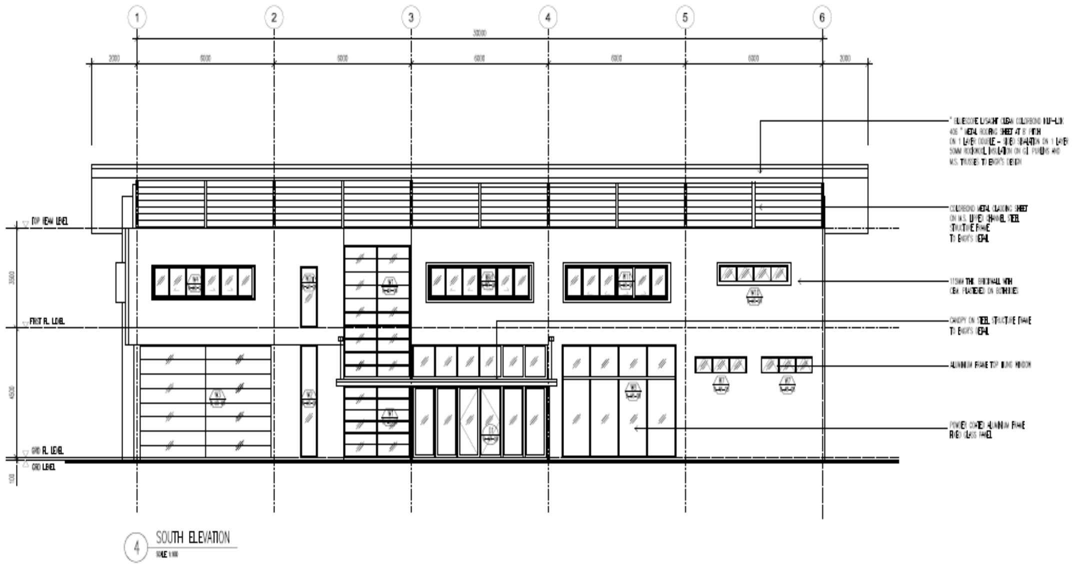


FIGURE 4.2. South Elevation of the Office Building

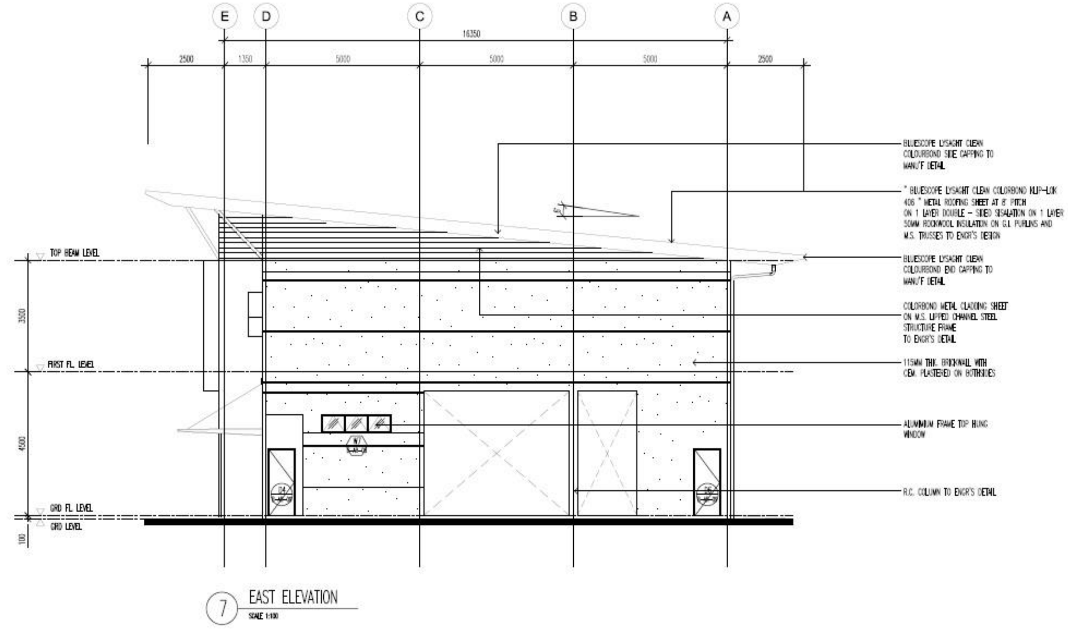


FIGURE 4.3. East Elevation of the Office Building

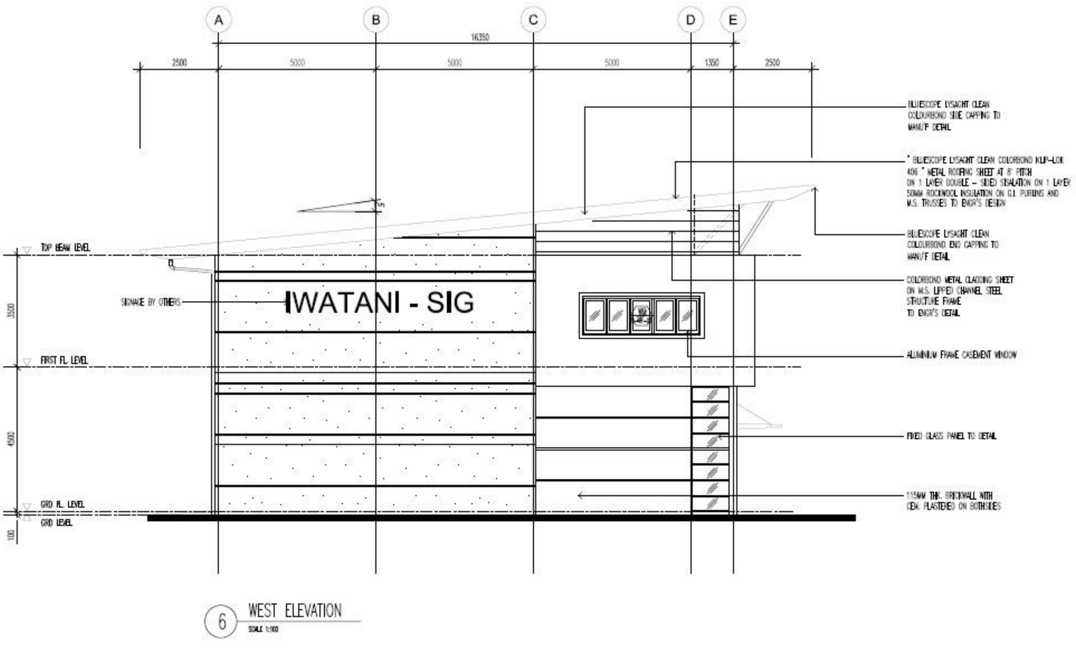


FIGURE 4.4. West Elevation of the Office Building

Figure 4.5 and 4.6 showing the components and its proposed location/arrangement of the office building for the ground floor as well as for the first floor.

FIGURE 4.5. Building Components and Its Arrangement (Ground Floor)

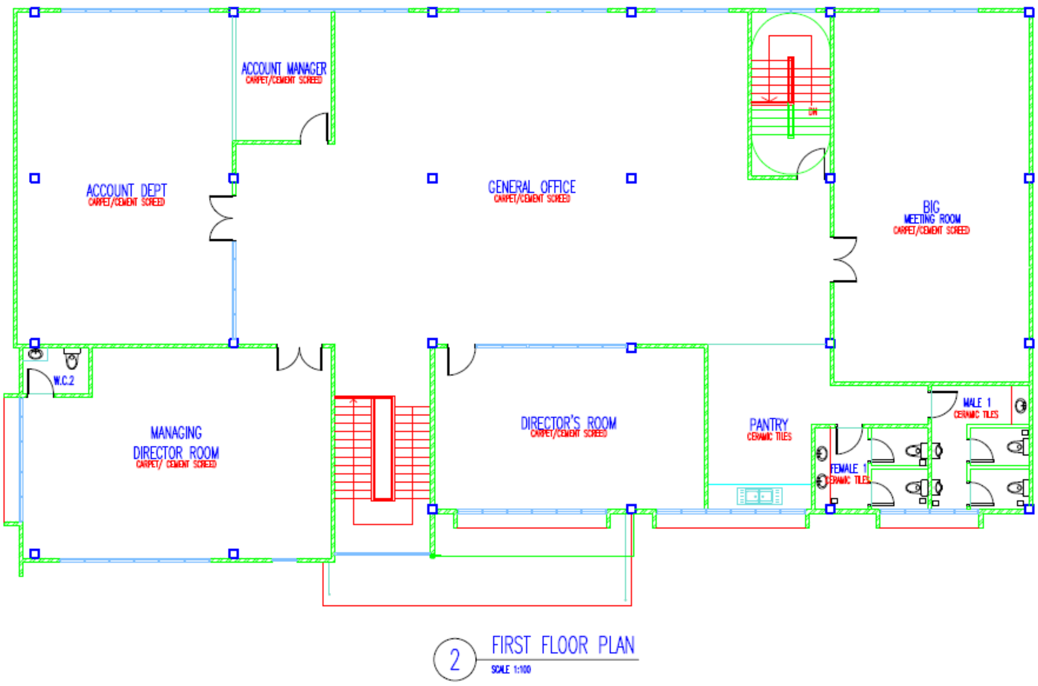


FIGURE 4.6. Building Components and Its Arrangement (First Floor)

4.2 Material Local Availability

The material transportation distance (km) will be determined by using UTP, Tronoh, Perak as the fixed destination location. Table 4.2 showing the local material availability nearest to UTP and their respective distance from UTP:

TABLE 4.2. The Materials' Local Availability

No.	Supplier/Company	Distance (km)
	Local Wood Suppliers	
1	Kam Seng Wood Industry - Chemor (Wooden door manufacturer)	55
2	Poh Hoe Chan - Taiping	94
3	Sun Seng Fatt Sdn Bhd - Ipoh	47
	Local Cement Suppliers	
1	YTL Cement Manufacturing – Ipoh (Green Concrete)	47
2	Associate Pan Malaysia Cement Sdn Bhd - Chemor	55
3	Lafarge Cement Sdn Bhd - Ipoh	47
	Local Bamboo Suppliers	
1	Bamboo Bio Composites Sdn Bhd, Gerik (Customization of dimension is possible)	156
2	Dagang Nusantara Sdn Bhd, Ipoh (Wood & Bamboo Products)	37
3	Green Bamboo Poultry Farming (M) Sdn Bhd - Taiping	94
	Local Steel Suppliers	
1	Ipoh	47
2	MSB Industries Sdn Bhd – Pusing	11
3	We on Engineering Sdn Bhd - Sitiawan	44
	Local Straw Bale Suppliers	
1	Diyou Future Biomass Sdn Bhd - Glenmarie, Shah Alam	215
2	FAZA Solution – Puchong, Selangor (Manufacturer, Other product: Paddy stalk - rice straw bale)	220
3	E-Wood Moulding (Malaysia) Sdn Bhd - Ipoh	47
4	Trilion Wood Works Sdn Bhd - Ipoh	47
	Local Bricks Suppliers	
1	Zairobina Sdn Bhd – Bagan Serai, Perak	119
2	Seng Lee Hardware Co – Taiping, Perak	96
3	Hup Fatt Trading Company – Kuala Dipang, Perak	30

4.2.1 Materials Justification

The construction materials which are to be utilised in the construction of the office building are justified by referring to the literature review extensively. The selection of the materials will be justified based on the performance, carbon-friendliness as well as the local availability of the material.

Concrete

Referring to Section 3.1.1 which discussing on the rationale of the selection of building material. The materials which made up the green concrete including the ground granulated blast furnace slag (GGBFS) / slag cement, recycled concrete aggregate (RCA) and recycled glass (crushed waste glass) could be found locally at YTL Cement Manufacturing at Ipoh, with distance of 47km. YTL Cement's products have significantly lower the levels of embodied CO_2, through use of the latest manufacturing equipment, energy efficient cement production processes and through cement and clinker replacement.

Wood

There are several manufacturers or suppliers of timber locally available in Ipoh, Perak. Wood is a natural resources and its renewable and sustainable criteria make it a popular material for sustainable construction. Gathering the advantages of wood as building material as compared to concrete, wood could be an effective means of reducing fossil fuel use and net CO_2 emission.

Bamboo

Bamboos are abundant and widely distributed locally in Malaysia. It has a huge potential as building material as indicated in Section 2.2.3. Bamboo Bio Composites Sdn Bhd which situated at Gerik, Perak (156km away from UTP) focuses on the research and development, production, marketing and distribution of bamboo lamella. The company has initiated research and development together with Universiti Putra

Malaysia (UPM) and FRIM for 7 years to discover the potential of bamboo as building materials and furniture components.

Straw Bale

Straw is an agricultural by-product. It is having wide benefits which help in fulfilling in the green concept to some extend due to its tremendous features, as discussed earlier in Section 2.2.5. Besides that, straw is easily accessible and it is locally available at Shah Alam, Selangor which situated around 220km from UTP.

4.3 Material Quantities

The following calculations showing the approximate quantities of the materials required for the construction of the different sections of the office building.

<u>Calculations:</u>

Volume of building = 8.0m * 16.35m * 30.0m = 3924 m^3

Wall

Assuming wall thickness = 6 inch = 15.24cm = 0.1524m

North and South Elevation	East and West Elevation
= (8.0m * 30m * 0.1524m) * 2	= (8.0m * 16.35m * 0.1524m) * 2
= 73.152 m^3 = 80 m^3	= 39.87 m^3 = 40 m^3

Total volume of wall = 80 + 40 = 120 m^3

Flooring

Ground Floor (GF): 24m * 16.35m = 392.4 = 400 m^2

First Floor (FF) : (30 *16.35) – (10 * 3.75) – (2.1 * 1.5) = 449.85 = 450 m^2

Total volume of floor = 400 + 450 = 850 m^3

4.4 Carbon Footprint Comparison

In this section, the conventional and alternative building materials will be compared in terms of their carbon dioxide equivalency (CO_2e) by measuring the greenhouse gas impacts of the construction activities for respective material, using the carbon calculator. The major information required for the calculation including the material quantities and its local availability are inputted into the carbon calculator in order to obtain the carbon footprint of respective building material.

Table 4.3 showing the summary of the carbon footprint for the conventional and alternative building materials for its utilisation in different building sections.

TABLE 4.3. Carbon Footprint Comparison of Conventional and Alternative Building Materials

Materials	Quantities	Transportation Distance (km)	Carbon Emission Factor	Carbon Footprint (tCO_2e)
External Wall				
Conventional Concrete	120 m^3	Ipoh – 47km	0.083	61.0
Green Concrete		Ipoh – 47km	*varies	28.9
Straw Bale		Selangor – 220km	0.04108	0.93
Internal Wall				
Conventional Concrete	120 m^3	Ipoh – 47km	0.083	61.0
Bricks		Kuala Dipang – 30km	0.240	55.4
Green Concrete		Ipoh – 47km	*varies	28.9
Concrete Reinforcement				
Steel	9 tonnes	Ipoh – 47km	1.46	13.2
Bamboo		Taiping – 94km	0.0020412	0.11
Flooring				
Concrete	850 m^3	Ipoh – 47km	0.083	433.0
Wood		Ipoh – 47km	0.240	125.0
Bamboo		Taiping – 94km	0.0020412	3.6

For the quantities breakdown of the conventional concrete and green concrete, on the research journal by Ahmad, 2007, entitled "Optimum Concrete Mixture Design using Locally Available Ingredients", the optimum coarse aggregate (CA) /total aggregate (TA) and total aggregate (TA) / cement (c) are identified to be 0.62 and 4.88 respectively based on the results of the experimental work conducted. The quantities breakdown of the concrete is essential for the calculation of carbon footprint of the building materials.

The proportion of the materials used in the concrete is shown as the calculation below:

<u>Calculation</u>:

$$\frac{CA}{TA} = 0.62, \qquad \frac{TA}{C} = 4.88$$

Assuming	TA + C = 120 m^3	TA = 99.6 m^3
	4.88C + C = 120	CA = 0.62 * TA
	C = 20.44 m^3	= 61.8 m^3
	TA = 4.88 * C	FA = 0.38 * TA
	= 99.6 m^3	= 37.8 m^3

Table 4.4 showing the quantities breakdown of the conventional concrete and green concrete after the calculation:

TABLE 4.4. The Quantities Breakdown of Conventional Concrete and Green Concrete

	Quantities (m^3)	Proportion (%)	Quantities Breakdown (m^3)
Conventional Concrete	120		
Portland Cement	20.4	100	20.4
Coarse Aggregate (CA)	61.8	100	61.8
Fine Aggregate (FA)	37.8	100	37.8
Green Concrete	120		
Portland Cement		50	10.2
Slag Cement		50	10.2
Virgin Rock (CA)		50	30.9
Recycled Concrete Aggregate		50	30.9
Virgin Sand (FA)		48	18.1
Waste Glass		52	19.7

The quantities breakdown of the conventional and green concrete is used as the input into the carbon calculator in order to obtain their respective carbon dioxide equivalency for both the concrete.

4.5 Results Analysis

4.5.1 Carbon Footprint Comparison for Building Materials

In order to analyse the results obtained from the calculator, the carbon footprint in term of tCO_2e for both conventional and alternative building materials used in different building sections are presented graphically as follow:

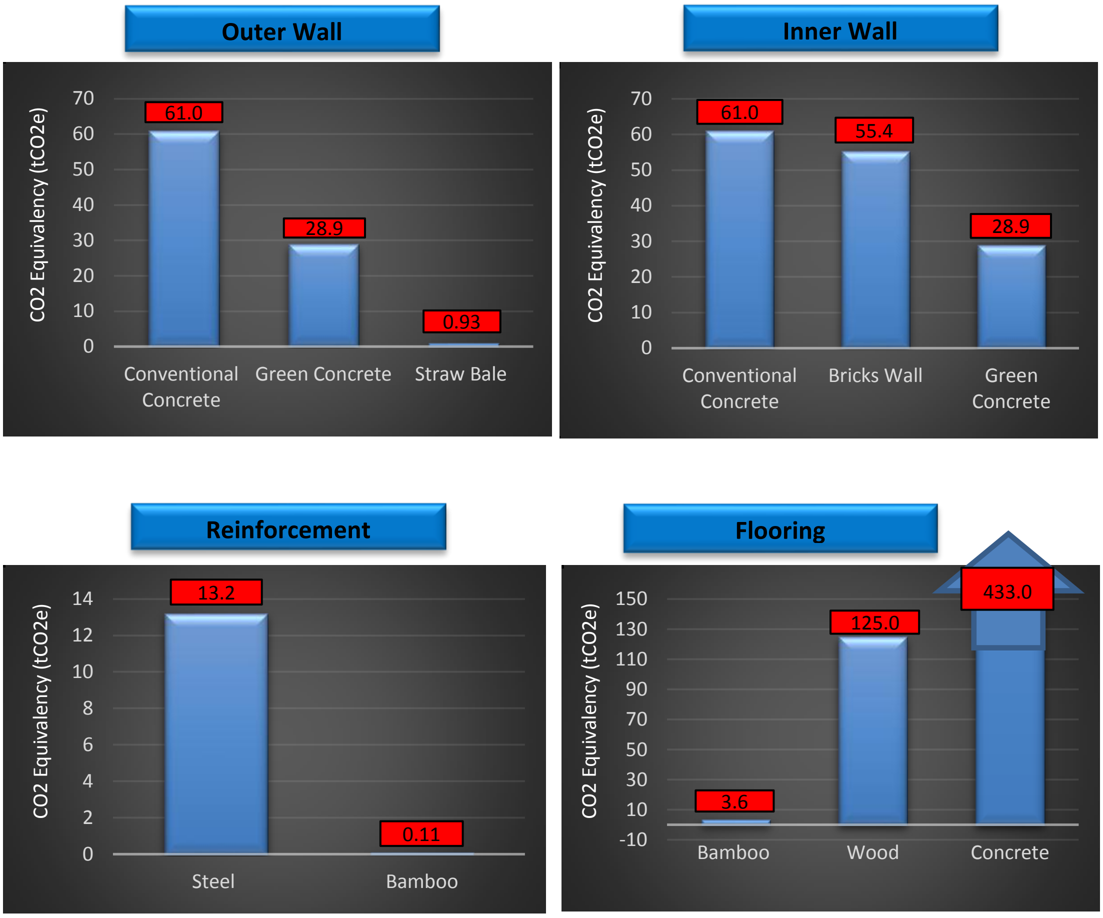


FIGURE 4.7. Carbon Dioxide Equivalency of Conventional and Alternative Building Materials for Different Building Sections

From the graphs, for the external wall built with green concrete, it contributes about merely half carbon footprint (28.9 tCO_2e) of that with conventional concrete (61.0 tCO_2e), and straw bale is having less than 1.0 tCO_2e carbon footprint, although its local availability distance is in Kuala Lumpur which is more than 200km away. Green concrete appeared to be a rational selection for the construction of both external and internal wall for the proposed building since it emits lesser carbon dioxide to the environment, and at the same time, the green concrete with right proportion of mixtures (50% on the conventional concrete mixture and 50% on recycled mixtures) are able to provide higher compressive strength, lower permeability and substantial durability for the building construction.

Moreover, the treated bamboo reinforcement, with carbon footprint of 0.11 tCO_2e is proved to have longer service life and better durability than the steel reinforcement (13.2 tCO_2e) in concrete. The bamboo reinforced concrete beams and columns are able to perform as good as the conventional steel reinforcement in normal concrete, as discussed and based on the research by Ghavami, (2005) on bamboo as reinforcement in structural concrete elements. With the carbon friendliness capability of the materials, it is indicated that bamboo can substitute steel satisfactorily and the structure elements developed could be used in different building constructions.

For office flooring, bamboo or hardwood is preferable because of its environmental friendly characteristics. Wood flooring has service life last for hundreds of years. It is completely biodegradable and can be easily be recycled at the end of its service life or being used as fuel. Besides that, bamboo is one of the fastest growing plants with a harvest cycle of just 3-5 years making it very renewable. FRIM has given very high priority for the bamboo development, both in terms of growth and manufacturing aspects, to discover and realize the bamboo potential as building materials.

4.5.2 Carbon Reduction (Percentage)

Table 4.14 showing the total carbon footprint reduced in percentage, taking the conventional building materials as the control combination.

TABLE 4.5. The Total Carbon Footprint Percentage Reduction

Conventional		Alternative 1		Alternative 2	
	Carbon Footprint		Carbon Footprint		Carbon Footprint
External Wall					
Conventional Concrete	61.0	Green Concrete	28.9	Straw Bale	0.93
Internal Wall					
Conventional Concrete	61.0	Bricks	55.4	Green Concrete	28.9
Reinforcement					
Steel	13.2	Bamboo	0.11	Bamboo	0.11
Flooring					
Concrete	433.0	Wood	125.0	Bamboo	3.6
Total Carbon Footprint (tCO_2e)	568.2		209.41		33.54
Percentage Reduction (%)	(As Control Value)		63.15%		94.10%

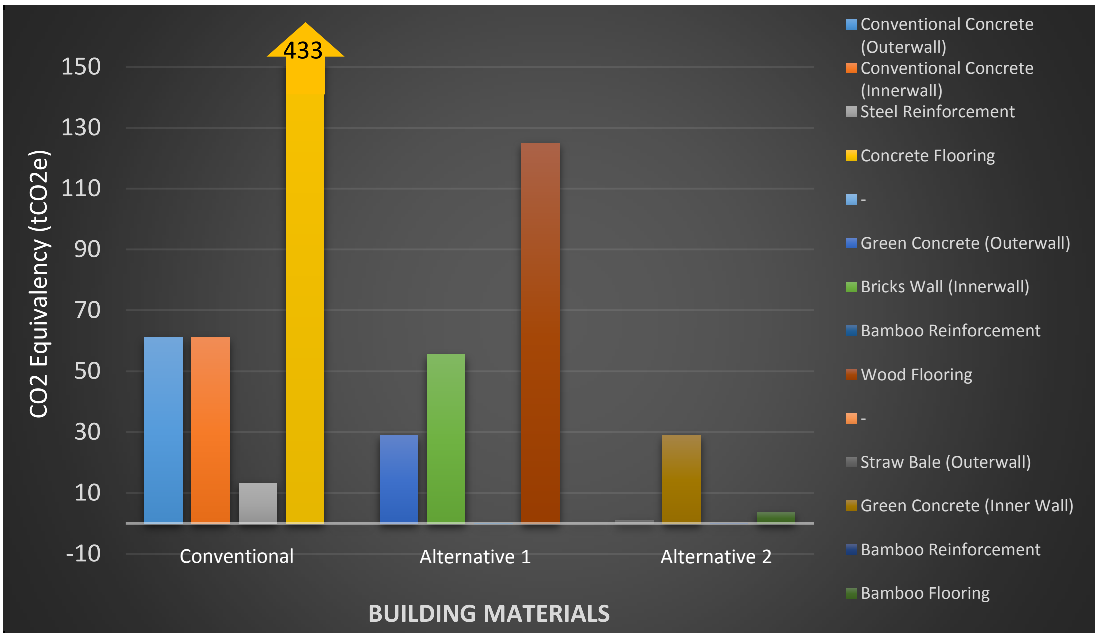


FIGURE 4.8. Comparison on Carbon Dioxide Equivalency of Conventional and Alternative Building Materials

Summing up all the carbon footprint produced by the conventional building materials in different building sections (conventional concrete for external, internal wall and the flooring, steel reinforcement in concrete), the total carbon footprint is used as a control value to be compared with the alternative building materials. The alternative 1 which consists of green concrete as outer wall, inner bricks wall, bamboo reinforcement and wood flooring, is able to reduce the total carbon footprint of the conventional building materials by 63.15%, while alternative 2 (straw bale as outer wall, green concrete inner wall, bamboo reinforcement and flooring) can even reduce the carbon footprint up to 94.10% when compared to the conventional building materials.

The results showed that a considerable amount of embodied carbon dioxide are able to be avoided by utilising the alternative native building materials. The building materials are justified and are able to provide greener solution for sustainable buildings.

CHAPTER 5:

CONCLUSION AND RECOMMENDATIONS

The project has proved that the alternative building materials are able to reduce the environmental impact of the materials used in building construction, and less usage of ore-based materials in building construction can be achieved. The embodied carbon emitted during the manufacture, transport and construction phase are able to be reduced profusely by utilising the alternative building materials in building construction.

The reduction of carbon footprint is being studied, researched and practiced all over the world. It is getting a major concern not only in construction industry, but also manufacturing, transportation and other sectors that causing threat to our environment. Moreover, carbon footprint is essential for sustainability of a building, a city, and even our daily life to reduce the exploitation of Earth’s resources and for the protection of our environment.

The study is expected to act as the motivation and guideline for designers/engineers for the future research in building construction. Reviewing on the importance of carbon footprint reduction and the positive contribution of environmental-friendly materials on the minimal impact to the environment, the research and utilization of the alternative building materials on newly or renovating building are highly encouraged and should be practiced widely in order to achieve sustainability in the building construction for the conservation and preservation of our environment.

REFERENCES

Ahmad, S. (2007). "Optimum Concrete Mixture Design Using Locally Available Ingredients." The Arabian Journal for Science and Engineering, Volume 32, Number 1B 27-33.

Bhattarai, P., Dhakal, D. R., Neupane, K., & Chamberlin, K. S. (2012). *Straw Bale in construction of building and its future in India* 422-426.

Chen, S.-H., Wang, H.-Y., & Jhou, J.-W. (2013). Investigating the properties of lightweight concrete containing high contents of recycled green building materials. *Construction and Building Materials, 48*, 98-103.

CWC (Canadian Wood Council), 2002. Green by Design: Renewable, Durable, Sustainable Wood.

Elsayed, M. S. G. Straw Bale is Future House Building Material

Environmentally Sustainable Building Materials - Selection. (2012, July).

E.Glavinich, T. (2008). *Contractor's Guide to Green Building Construction*. New Jersey: John Wiley & Sons, Inc.

Franzoni, E. (2011). Materials Selection for Green Buildings: which Tools for Engineers and Architects? *Procedia Engineering, 21*, 883-890.

Ghavami, K. (2005). Bamboo as reinforcement in structural concrete elements. 637-649.

Green Building. (2013, December 19). *U.S. Environmental Protection Agency*. Retrieved from http://www.epa.gov/greenbuilding/index.htm

Gustavsson, L., & Sathre, R. (2006). Building and Environment. *Variability in energy and carbon dioxide balances of wood and concrete building materials*, 940-951.

Hoang, C. P., Kinney, K. A., & Corsi, R. L. (2009). Ozone removal by green building materials. *Building and Environment, 44*(8), 1627-1633.

How to Live a Low-Carbon Lifestyle. (2011). *GAIAM life*. Retrieved from http://life.gaiam.com/article/how-live-low-carbon-lifestyle

J.Kibert, C. (2008). *Sustainable Construction - Green Building Design and Delivery*. New Jersey: John Wiley & Sons, Inc. .

Lee, B., & Neely, D. (2005, September 27). The Doyle Conservation Center - A Case Study of Challenges, Successes, Lesson Learned.

Maier, P. L., & Durham, S. A. (2012). Beneficial use of recycled materials in concrete mixtures. 428-437.

Mindess, Young, Darwin. Concrete. In: Horton Marcia, editor. 2nd ed. Upper Saddle River: Pearson Education, Inc.; 2003. p. 644.

Moskow, K. (2008). *Sustainable Facilities - Green Design, Construction and Operations*: McGraw Hill.

Ogunkah, I., & Yang, J. (2012). Investigating Factors Affecting Material Selection: The Impacts on Green Vernacular Building Materials in the Design-Decision Making Process. *Buildings, 2*(4), 1-32. doi: 10.3390/buildings2010001

Optimize Building Space and Material Use. (2013, April 9). *Whole Building Design Guide (WBDG)*. Retrieved from http://www.wbdg.org/design/env_preferable_products.php

Proske, T., Hainer, S., Rezvani, M., & Graubner, C.-A. (2013). Eco-friendly concretes with reduced water and cement contents — Mix design principles and laboratory tests. *Cement and Concrete Research, 51*, 38-46. doi: 10.1016/j.cemconres.2013.04.011

Reducing the environmental impact of building materials (2011, March 10).

Sathre, R., & O'Connor, J. (2010). The Synthesis of Research on Wood Products and Greenhouse Gas Impacts.

The Impact of Constructions and the Built Environment. (2010, December).

Wang, L., Toppinen, A., & Juslin, H. (2014). Use of wood in green building: a study of expert perspectives from the UK. *Journal of Cleaner Production, 65*, 350-361.

Yu, D., Tan, H., & Ruan, Y. (2011). A future bamboo-structure residential building prototype in China: Life cycle assessment of energy use and carbon emission 2638-2646.

Zinzi, M., & Agnoli, S. (2012). Cool and green roofs. An energy and comfort comparison between passive cooling and mitigation urban heat island techniques for residential buildings in the Mediterranean region. *Energy and Buildings, 55,* 66-76.

Zuo, J., & Zhao, Z.-Y. (2014). Green building research–current status and future agenda: A review. *Renewable and Sustainable Energy Reviews, 30*, 271-281.